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Observed changes in precipitation in China-Pakistan economic corridor during 1980–2016

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A R T I C L E I N F O

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Precipitation trend
Monsoon precipitation

A B S T R A C T

Changes in precipitation have been widely considered as a critical indicator of climate change. This is of prime importance to assess the strength and magnitude of these changes on regional and local scale. To document the observed changes in precipitation over China- Pakistan Economic Corridor (CPEC), the current study was conducted with monthly precipitation data from 53 meteorological stations across the CPEC. The non-parametric Mann- Kendall (MK), Sen's Slope (SS) estimator, and Sequential Mann-Kendall (SQMK) tests were used to assess the trends in precipitation data during 1980 to 2016. The results indicated that winter and post-monsoon precipitation were decreased at the rates of −0.26 and −0.02 mm per year, respectively. Monsoon, pre-monsoon and annual precipitation increased at the rates of 0.14, 0.13, and 0.02 mm per year, respectively. The spatial distribution of trends for seasonal and annual precipitation over different sub-climatic regions indicated that the trend is dynamic and varies from station to station. The station with SS and MK tests for the winter precipitation data showed an increasing (decreasing) trends at 14 (39) stations and only 1 (7) are significant at 0.05 level, respectively. The pre-monsoon, monsoon, post-monsoon, and annual precipitation indicated a positive (negative) trends over 40 (13), 31 (22), and 35 (18), 28 (25) stations with 3 (1), 5 (2), 2, 6 (7) significant stations at significance level of 0.05, respectively. The maximum positive and negative trends were detected at Parachinar (1.82 mm/year) and Dir (−1.86 mm/year) stations in pre-monsoon and winter precipitation, respectively. The mutations in temporal trends of seasonal and annual precipitation are very complex and dynamic during the study period. In winter, the rapid downward shifts were observed in 1984 and 1995. The mutations in pre-monsoon precipitation occurred after 1996s with a rapid upward/downward shift in 1997/2000. The monsoon precipitation shows a rapid decreasing shift since 1989 and an abrupt upward change in 2011. In post-monsoon precipitation, the rapid downward and upward changes were detected in 1989 and 1999, respectively. The mutations in annual precipitation were found in the first decade of the study period with a steep increase in 1982 and abrupt decrease in 1986. With respect to elevation dependency, the trend of long-term precipitation fluctuates and show a significant increasing trend in elevation zones of ≤500 m and ≥ 1500 m, while the trend decreases in 500–1000 m and 1000–1500 m elevation zones. Moreover, the winter, monsoon and annual precipitation shows negative correlation with elevation, while the pre-monsoon and post-monsoon precipitation show positive correlation with elevation. The findings of this study will help to address the problems of climate change and hydro-meteorological disasters in the regions. Further studies should focus on the climatic drivers of these changes in the regions.

1. Introduction

Precipitation is a key variable to study the climate and hydro-meteorology of a region. Changes in precipitation may lead to flood, drought, loss of biodiversity, agricultural productivity, and hydropower generation (Hu et al., 2016; Moazami et al., 2016; Sun et al., 2015; Zhang et al., 2015a, 2015b). The Intergovernmental Panel on Climate Change (IPCC) indicated that global warming has significantly affected

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the precipitation patterns both spatially and temporally (IPCC, 2013). Changes in seasonal and annual precipitation are considered to be the critical indicators of climate change (Chou et al., 2013; Sorg et al., 2012). Therefore, detecting past trends, rapid mutation and variability in precipitation have become a core area of research in recent years (Ahmad et al., 2015; Xu et al., 2018). The accurate trend detection in precipitation can play a vital role in regional climate assessment and water resource management (Karpouzos et al., 2010; Rahman and Begum, 2013). Statistical techniques could be extended to analyze the trend in precipitation (Sharma et al., 2016). Until now, various statistical methods have been developed and employed for detection and shift of trend in precipitation time series (Jha and Singh, 2013; Martinez et al., 2012; Tabari et al., 2011). Among these, parametric and non-parametric methods are commonly used. The non-parametric method is preferred over parametric method because of non-normal distribution of data series (Sonali and Kumar, 2013).

Climate change studies have recognized that the spatio-temporal variations in precipitation exist between climatically different regions (Zhang et al., 2013). The amount of global land precipitation has been increased by 2% during the last century (New et al., 2001); however, this increase has not been homogenous both spatially and temporally (IPCC, 2013). The annual precipitation in Central Asia (Hu et al., 2016, 2017; Li et al., 2016) and Hindu Kush Himalayan Region of Tibetan Plateau (Ren et al., 2017; You et al., 2017) show increasing trends in recent decades. A significant positive trend was found in mean annual precipitation over the Northwestern China (Li et al., 2016), while a downward trend has been recorded in annual precipitation in Yellow River Basin of China (Zhang et al., 2014) during the last few decades. The annual precipitation shows a positive trend over India. (Subash and Sikka, 2014). Similarly, a significant upward trend was observed in annual, monsoon and pre-monsoon precipitation in Bangladesh (Endo et al., 2015; Shahid, 2010, 2011). Decreasing trend in mean annual precipitation was found over Iran during the last fifty years (Tabari and Talaee, 2011).

Various studies have been conducted to detect time-space trends in annual and seasonal precipitation in Pakistan (Asmat and Athar, 2017; Hartmann and Buchanan, 2014; Sheikh et al., 2015). An overall increasing trend in annual precipitation has been observed over northwestern Pakistan (Ahmad et al., 2015; Gadiwala and Burke, 2013), while significant decreasing trend was found over southern parts of the country (Hanif et al., 2013). Moreover, the annual precipitation shows an upward trend in southwestern parts of Pakistan while the central parts show a decreasing trend in annual precipitation (Hussain and Lee, 2014). Similarly, in the northern and northeastern highlands of Pakistan, the annual and monsoon precipitation is increasing, while in the southeast region, the post-monsoon precipitation shows an increasing trend (Ahmed et al., 2017). The southern Punjab region of Pakistan experiences a decreasing trend in annual precipitation (Abbas et al., 2014). The above cited studies have provided detail information about the precipitation trend over different parts of the country. However, these studies are either limited to a small region, low station density, short temporal coverage or different data sources. Thus this study is an improvement in terms of the CPEC region, intended time scale, stations' density, and data source. Moreover, no attempt has been made so far, to conduct a detail study on the analysis of extreme temperature events over CPEC. Therefore, the present study focused on assessment of the spatio-temporal changes in precipitation over China- Pakistan Economic Corridor (CPEC). The current study is the first of its nature being conducted on climate change perspective in the CPEC region.

The CPEC is a flag project of the Belt and Road Initiative (BRI) and will play a significant role in regional integration and development in near future (Irshad et al., 2015; Qureshi, 2015). Related studies revealed that the regions along the CPEC routes are highly sensitive to climate change due to recent global warming trends (Asmat and Athar, 2017; Iqbal and Athar, 2018; Yamada et al., 2016). Therefore, it needs more attention to study the variability and tendencies of precipitation patterns in the target area for climate friendly planning. The present study aims to analyze the precipitation variability and to detect the spatio-temporal trend of precipitation over the CPEC routes during 1980–2016. For this purpose, we used various statistical methods and techniques. The non-parametric Mann-Kendall (MK) test was employed to detect the significant monotonic trend; the Sen's Slope (SS) estimator test was used to quantify the magnitude/slope of the trend; the Sequential Mann-Kendall (SQMK) test was applied to detect the abrupt temporal shift or change in the trend. The analyses were carried for the CPEC as well as for three climatic regions: Region-1 (R-1), Region-2 (R-2), and Region-3 (R-3) on annual and seasonal (winter, pre-monsoon, monsoon, and post-monsoon) basis.

2. Study area

The China-Pakistan Economic Corridor (PEC) is a pilot project of the Belt and Road Initiative (BRI) (Abid and Ashfaq, 2016). The CPEC is extended from northeast to South of Pakistan with geographical coordinates of $25^0\ 24'$ to $36^0\ 10'$ North latitude, and $63^0\ 21'$ to $74^0\ 59'$ East longitude. It connects the Pakistani Port of Gawadar to Chinese City of Kashgar (Markey, 2016). The CPEC consists of two main routes with a total length of 4918 km, i.e. Western route and Eastern route. The western route is located in the West of Pakistan, passes through most parts of the Khyber Pakhtunkhwa and Baluchistan Provinces, while the eastern route is located in the East of Pakistan, encompasses the major parts of the Punjab and Sindh provinces. The CPEC is intended to promote connectivity across Pakistan with a network of highways, railways, and pipelines accompanied by energy, industrial, and other infrastructure development projects in order to boost Pakistan's economic growth (Markey, 2016). Subject to the prime location of the Gawadar port, the corridor gives China's access to South Asia, Middle East, Africa, and Europe (Ahmar, 2016; Chaziza, 2016). The CPEC is stretched from North to South of Pakistan and its network of highways, railways, and industrial zones will be extended to the whole country. Therefore, the whole Pakistan is considered as a study area in this paper.

Pakistan is located in South Asian region with geographical coordinates of $23.6^0 - 38^0$ North latitude and 61^0–78^0 East longitude. The country covers an area of 796,096 km^2. Pakistan has a diverse and complex landscape ranging from world famous Himalayas and Karakoram mountains in the North and northwest, with flat agricultural plains of Indus River Basin in the Centre and coast of Arabian Sea in the South (Ashiq et al., 2010). The elevation of the area ranges from 0 to 8611 m above sea level in the North with world's second highest mountain peak Mount Godwin-Austin (K2). Most parts of the country are arid to semi-arid with significant spatio-temporal variability in climatic conditions. The northern parts of the country are dominated by humid to arid climate while the southern parts are dominated by coastal climate. Similarly, the tropical and continental climate can be observed in the central parts of the country (Asmat and Athar, 2017). Precipitation over Pakistan is mainly subjected to two types of weather systems: summer and winter precipitation (Khan et al., 2014). Due to large topographic and temperature contrast, the precipitation pattern is multifarious in Pakistan during both summer and winter seasons (Hanif et al., 2013; Hussain and Lee, 2013). The monsoon depressions originating from the Bay of Bengal enters in the country from East to northeast during the months of July to September with high intensity (~55% to 60% of annual budget) (Asmat and Athar, 2017; Hussain and Lee, 2013). The winter precipitation occurs as a result of Westerly disturbances originating from the Mediterranean Sea and enters in the country from northeast to southeast during the months of December to March with moderate intensity (~30% of annual budget) (Asmat et al., 2017; Dimri et al., 2015; Wang et al., 2011). Both the summer and winter precipitations account for more than ~90% of the annual precipitation budget.

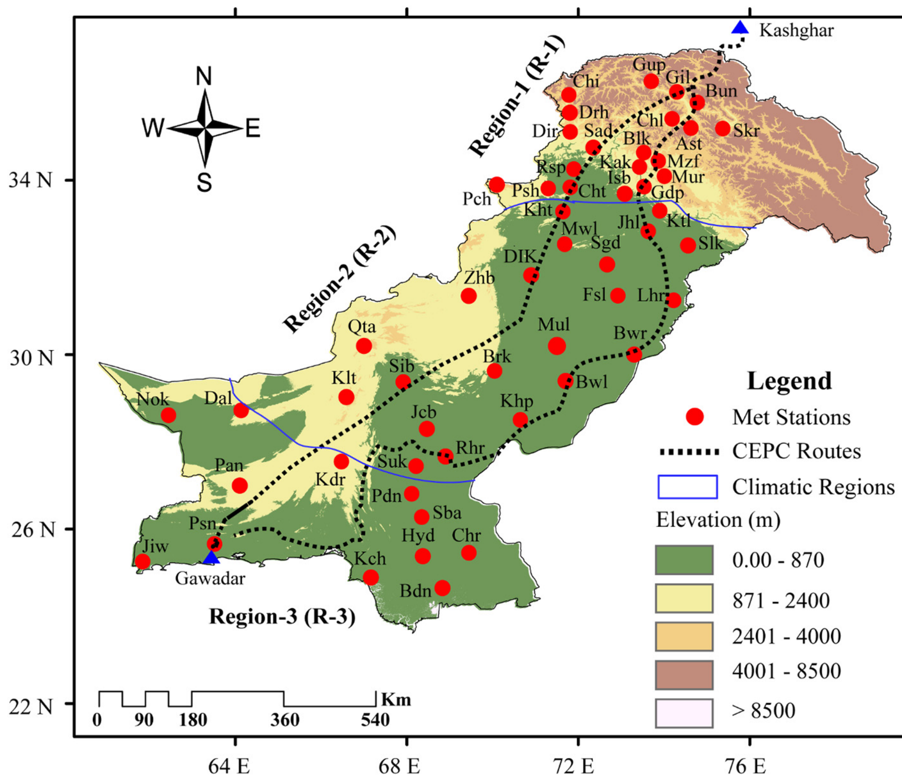

Fig. 1. Location of the CPEC routes and selected meteorological stations.

3. Materials and methods

3.1. Data

Monthly precipitation datasets of 53 stations for the period of 1980 to 2016 were obtained from Pakistan Meteorological Department (PMD). The detail information of the selected stations is shown in Fig. 1 and Table 1. The stations were selected on the basis of their proximity to the CPEC routes, and time period of data. The monthly values were summed up to obtained the seasonal and annual scale precipitation datasets. Seasons were defined as follows: winter (December, January, February, March), pre-monsoon (April, May, June), monsoon (July, August, September), and post-monsoon (October, November). Moreover, the whole region is divided to into three sub-climatic regions i.e. Region-1 (R-1), Region-2 (R-2) and Region-3 (R-3). The northern part of the country is considered as R-1. It is comprised of the high mountainous regions with humid to arid climate, while the central part of the country is considered as R-2. This region is dominated by Indus plains with tropical and continental climate (Asmat and Athar, 2017). The southern part of the country is considered R-3. This region is located along the coast of Arabian Sea and is dominated by coastal climate (Ashiq et al., 2010). Moreover, the regional mean precipitation of seasonal and annual time series were calculated by taking the average values of all stations located in each region.

3.2. Methods

Before applying the Mann- Kendall (MK), Sen's Slope (SS) estimator, and Sequential Mann-Kendall (SQMK) tests (Kendall, 1955; Mann, 1945; Sonali and Kumar, 2013) to detect the trends in precipitation time series, the data were tested according to the tests' requirement. All the datasets of seasonal and annual precipitation were tested using autocorrelation test. Moreover, the pre-whitening approach was applied to remove the autocorrelation in datasets. MK test was used to detect the monotonic trend, while the SS estimator test was used to quantify the slope of trend in precipitation time series. Similarly, the SQMK test was used to detect abrupt change or shift in the trend over time. The relationship between precipitation trend and elevation was assessed by linear regression equation. These statistical methods are briefly discussed below.

3.2.1. Autocorrelation test

Autocorrelation or serial correlation is one of the main problems in testing and interpreting time series data (Ahmad et al., 2015). Though the trend is not present in a time series, the presences of autocorrelation would add significant trend to the time series and would affect the outcomes of the MK test (Hamed and Rao, 1998; Partal, 2009). Therefore, the significant autocorrelation should be checked and removed before applying the MK test (Sonali and Kumar, 2013). The following steps are adopted to check the autocorrelation in different time series.

I. Compute the lag-1 serial correlation coefficient of the different time scales about precipitation series as in Eq. (1) (He et al., 2015):

$$r1 = \left[\frac{1}{n-1}\sum_{i=0}^{n-1}(X_i - \overline{X}).\left(X_{i+1} - \overline{X}\right)\right] / \left[\frac{1}{n}\sum_{i=0}^{n-1}(X_i - \overline{X})^2\right] \tag{1}$$

Where r_1, X_n and X are the correlation coefficient lag-1, precipitation series, and mean of the precipitation time series, respectively.

II. The confidence interval (CI) of the correlation coefficient lag-1 (r_1) at the 5% significance level can be computed by eq. (2) (Y. Zhang et al., 2015):

$$r1\,(5\%) = (-1 \pm 1.96\sqrt{n} - 2)/(n-1) \tag{2}$$

If r_1 falls into the confidence limits (lag-1 ≥ 0.254 or lag-1 ≤ -0.254), the precipitation time series is independent, and the MK test can be applied directly. Otherwise, the MK test should be applied after the removal of the serial correlation, which can be computed as ($X_2 - r_1X_1$, $X_3 - r_2X_2$ .... $X_n - r_nX_n$) (Rashid et al., 2015).

Table 1
Information of selected meteorological stations and sub-climatic regions.

Code	Stations	Latitude (′)	Longitude (′)	Elevation (m)	Region
Ast	Astore	35.35	74.86	2168	Region-1
Blk	Balakot	34.55	73.21	995	
Bun	Bunji	35.67	74.63	1372	
Cht	Cherat	33.92	71.90	1372	
Chl	Chilas	35.42	74.10	1250	
Cht	Chitral	35.83	71.78	1498	
Dir	Dir	35.2	71.85	1375	
Drh	Drosh	35.55	71.85	1465	
Gdp	Gahridopatta	34.13	73.47	813	
Gil	Gilgit	35.92	74.33	1460	
Gup	Gupis	36.17	73.40	2156	
Isb	Islamabad	33.80	73.08	508	
Kak	Kakul	34.18	73.15	1308	
Mur	Murree	33.90	73.40	2134	
Mzf	Muzaffarabad	34.37	73.48	838	
Pch	Parachinar	33.90	70.10	1775	
Psh	Peshawar	34.02	71.58	328	
Rsp	Risalpur	34.07	71.98	304	
Sad	Saidu Sharif	34.73	72.35	961	
Skr	Sakardu	35.18	75.68	2317	
Bwr	Bahawalnagar	29.82	73.28	161	Region-2
Bwl	Bahawalpur	29.40	71.7	110	
Brk	Barkhan	29.88	69.72	1097	
DIK	D.I·Khan	31.49	70.56	171	
Fsl	Faisalabad	31.26	73.10	185	
Jcb	Jacobabad	28.18	68.28	55	
Jhl	Jhelum	32.56	73.44	287	
Klt	Kalat	29.03	66.35	2015	
Khp	Khanpur	28.39	70.41	88	
Kht	Kohat	33.45	71.53	564	
Ktl	Kotli	33.31	73.54	614	
Lhr	Lahore	31.35	74.24	214	
Mwl	Mianwali	32.58	71.55	205	
Mul	Multan	30.12	71.26	122	
Qta	Quetta	30.11	67.57	1719	
Rhr	Rohri	27.69	68.85	66	
Sgd	Sargodha	32.03	72.4	187	
Slk	Sialkot	32.31	74.32	255	
Sib	Sibbi	29.33	67.55	133	
Suk	Sukkar	27.42	68.52	68	
Zhb	Zhob	31.21	69.28	1405	
Bdn	Badin	24.38	68.54	9	Region-3
Chr	Chhor	25.31	69.47	5	
Dal	Dalbandin	28.53	64.24	848	
Hyd	Hyderabad	25.23	68.25	28	
Jiw	Jiwani	25.04	61.80	56	
Kch	Karachi	24.89	67.16	22	
Kdr	Khuzdar	27.5	66.38	1231	
Nok	Nokkundi	28.49	62.45	682	
Pdn	Padidan	26.51	68.08	46	
Pan	Panjgur	26.58	64.10	968	
Psn	Pasni	25.22	63.28	9	
Sba	Shaheed Benazirabad	26.15	68.22	37	

3.2.2. Mann Kendall test

MK test is a non-parametric test, which can be used to detect statistically significant trend in precipitation time series (Kendall, 1955; Mann, 1945; Sonali and Kumar, 2013). The test has been widely used by different authors to detect trend in hydro-meteorological time series (Abbas et al., 2014; Chen et al., 2016; Gocic and Trajkovic, 2013; Yang et al., 2017). However, it has been found that the MK test is sensitive to serial correlation and the presences of serial correlation in the time series can affect the results of MK test (Salman et al., 2017). The pre-whitening approach can be used to remove the serial correlation from the time series (Ahmad et al., 2015; Chen et al., 2016). Therefore, we used the same approach to remove the serial correlation from the data sets before applying the MK test. On the other hand, the modified Mann Kendall Test (m-MK) is effective to account the effect of serial correlation (Hamed and Rao, 1998; Partal, 2009). The present study prefers the MK test over the m-MK version as the serial correlation was removed from the time series through pre-whitening method. Moreover, MK test is simple and robust against outliers, missing values, normal distribution, and has low sensitivity to abrupt breaks in time series (Salman et al., 2017; Shahid, 2010, 2011; Zamani et al., 2017).

The null hypothesis (H_0) of the test stated that there is no trend in the precipitation time series over time, while the alternate hypothesis (H_1) indicated that there is a monotonic trend (increasing or decreasing) over time. The mathematical equations for computing Mann Kendall statistics is defined by (Hirsch and Slack, 1984) in Eq. (3):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} Sgn\ (X_j - X_i) \tag{3}$$

Where Sgn (X_j− X_i) can be computed by Eq. (4)

$$\text{Sgn (Xj—Xi)} = \begin{cases} +1,\ if\ (\text{Xj—Xi}) > 0 \\ 0,\ if\ (\text{Xj—Xi}) = 0 \\ -1,\ if\ (\text{Xj—Xi}) < 0 \end{cases} \tag{4}$$

Where X_j, and X_i are the time series observations, and *n* is the length of the time series. For identically and independently distributed datasets with zero mean, the variance S_t of the statistics S is given in Eq. (5) (Nasri and Modarres, 2009):

$$\text{St} = \frac{1}{18}\left[n(n-1)(2n+5) - \sum\nolimits_{p=1}^{q} t_p(t_p-1)\left(2t_p+5\right)\right] \tag{5}$$

Where t_p is the number of ties for the *p*th value and q is the number of tied values. The MK test statistic, Z, can be computed from Eq. (6):

$$Z = \begin{cases} (S-1)/\sqrt{S_t}\ if\ S_t > 0 \\ \quad 0\ \ if\ S_t = 0 \\ S+1)/\sqrt{S_t}\ if\ S_t < 0 \end{cases} \tag{6}$$

Where values of statistical Z falls beyond the confidence interval of ± 1.96 indicate that the trend is statistically significant at the 95% significance level. The positive values of Z indicate that the trend is positive while the negative values represent a negative trend in the time series.

3.2.3. Sen's slope estimator

SS estimator is a non-parametric test proposed by (Sen, 1968) to quantify the slope of the trend in a time series. When a linear trend exist in a time series, then the slope estimates of N pairs of data can be computed by Eq. (7):

$$\text{Slope} = \text{Median}\ [(X_j - X_i)/(j-i)] \tag{7}$$

Where 1 < I < j < n, and n is the length of time series. A positive value of slope indicates an increasing slope, while a negative value of slope indicates a decreasing trend in precipitation time series.

3.2.4. Sequential Mann Kendall (SQMK) test

The SQMK test developed by (Sneyers, 1990) is used to determine the beginning of significant trend in a time series (Some'e et al., 2012; Sonali and Kumar, 2013). The abrupt changes in trend are estimated by the series of progressive (UF) and retrograde (UB). In this test, UF is a standardized variable with zero mean and unit standard deviation. Therefore, its sequential behavior fluctuates around the zero level. The nature of UF is same as the Z values that are starting from the first to last data point. Similarly, the value of UB is computed backward, starting from the end point to the first point of time series. This test considers the relative values of all terms in the time series (x_1, x_2, …, x_n). The following steps are applied in computing the SQMK test.

I. First, we compared the magnitudes of x_j annual mean time series (j = 1, …, n) with x_k,(k = 1, …,j − 1). The number of cases x_j > x_k are counted and the outcome is denoted by n_j.

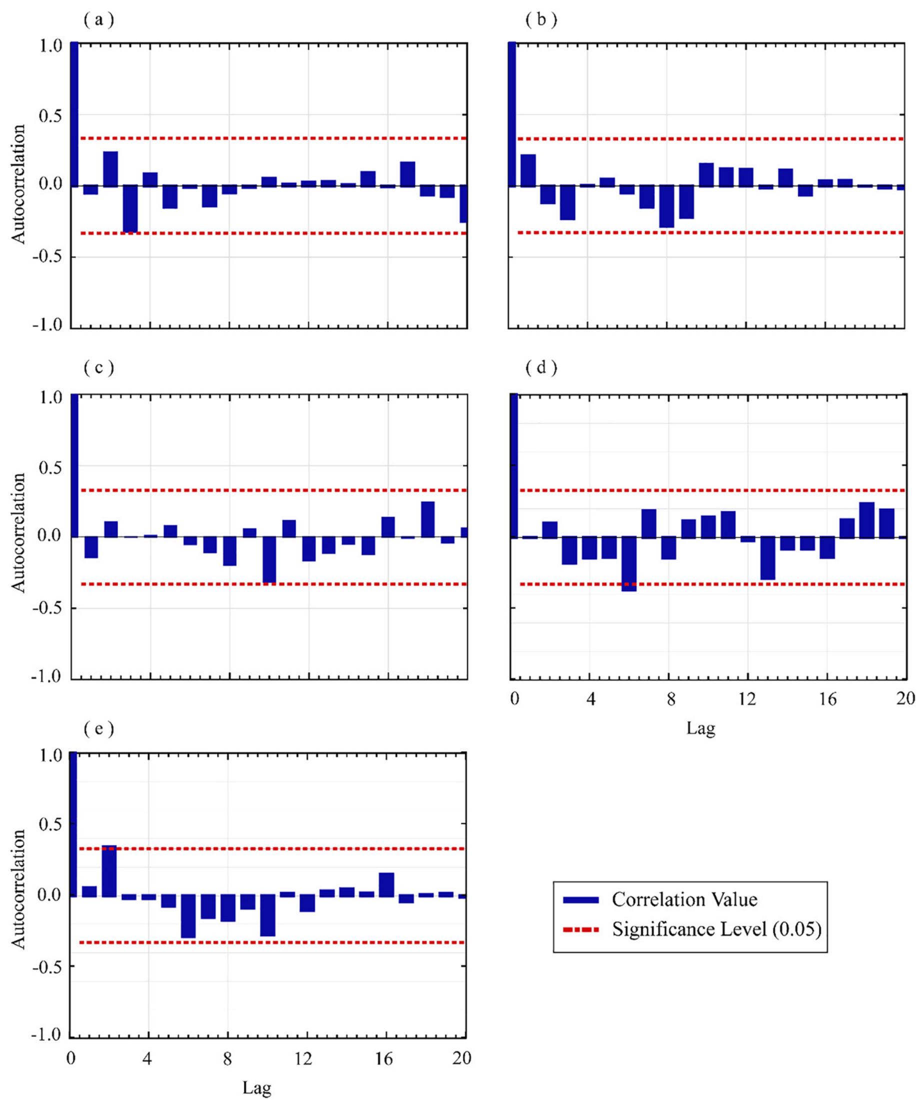

Fig. 2. Autocorrelation of seasonal and annual precipitation time series for different lags; (a) Winter, (b) Pre-Monsoon, (c) Monsoon, (d) Post-Monsoon, (e) Annual.

II. The test statistic t is obtained by Eq. (8):

$$tj = \sum_{1}^{j} n_j \tag{8}$$

III. The mean and variance of the t are computed by the Eqs. (9) and (10), respectively:

$$E\,(t) = [n\,(n-1)]/4 \tag{9}$$

$$Var\,(t_j) = j\,(j-1)\,(2j + 5)/72 \tag{10}$$

IV. At the end, the sequential values of UF and UB are calculated by Eq. (11):

$$UF\,(t) = [tj-E\,(t)]/\sqrt{var}\,(t_j) \tag{11}$$

If $|UF\,(t)| \le UF\,(t)_{1-\alpha/2,}$ where $UF\,(t)_{1-\alpha/2}$ is the critical value of the standard normal distribution with a probability value exceeding $\alpha/2$, the null hypothesis would be accepted at a significance level in the trend test. In this study, we set α value as 0.05. The decreasing values of UF and UB indicate a negative trend, while the increasing values represent a positive trend in the time series (Zarenistanak et al., 2014). The intersection points of UF and UB curves indicate the possible turning year of the trend within a time series (Tabari et al., 2012). The trend turning point is considered significant at the corresponding threshold level (i.e. ± 1.96 for 95% significance level).

3.2.5. Linear regression

The correlation of precipitation trend and elevation was analyzed by linear regression (equation: 12). The equation is expressed as:

$$Y = aX + b \tag{12}$$

Where X represents stations' elevation; Y is the precipitation trend; a and b are the regression slopes, and intercepts, respectively.

4. Results and discussion

4.1. Removal of autocorrelation

The correlation coefficients of the seasonal and annual precipitation time series in the study area at different lags are shown in Fig. 2. The analysis indicates that there is no autocorrelation in annual and seasonal time series at lag-1. However; few of the annual and post-monsoon time series reached the significant level of autocorrelation at different lags. Therefore, to avoid the effects of autocorrelation on MK test, all the significant autocorrelations were removed from the relevant time series using Eqs. (1) and (2).

4.2. Spatial distribution of seasonal and annual precipitation

Fig. 3 shows the spatial distribution of the mean seasonal and

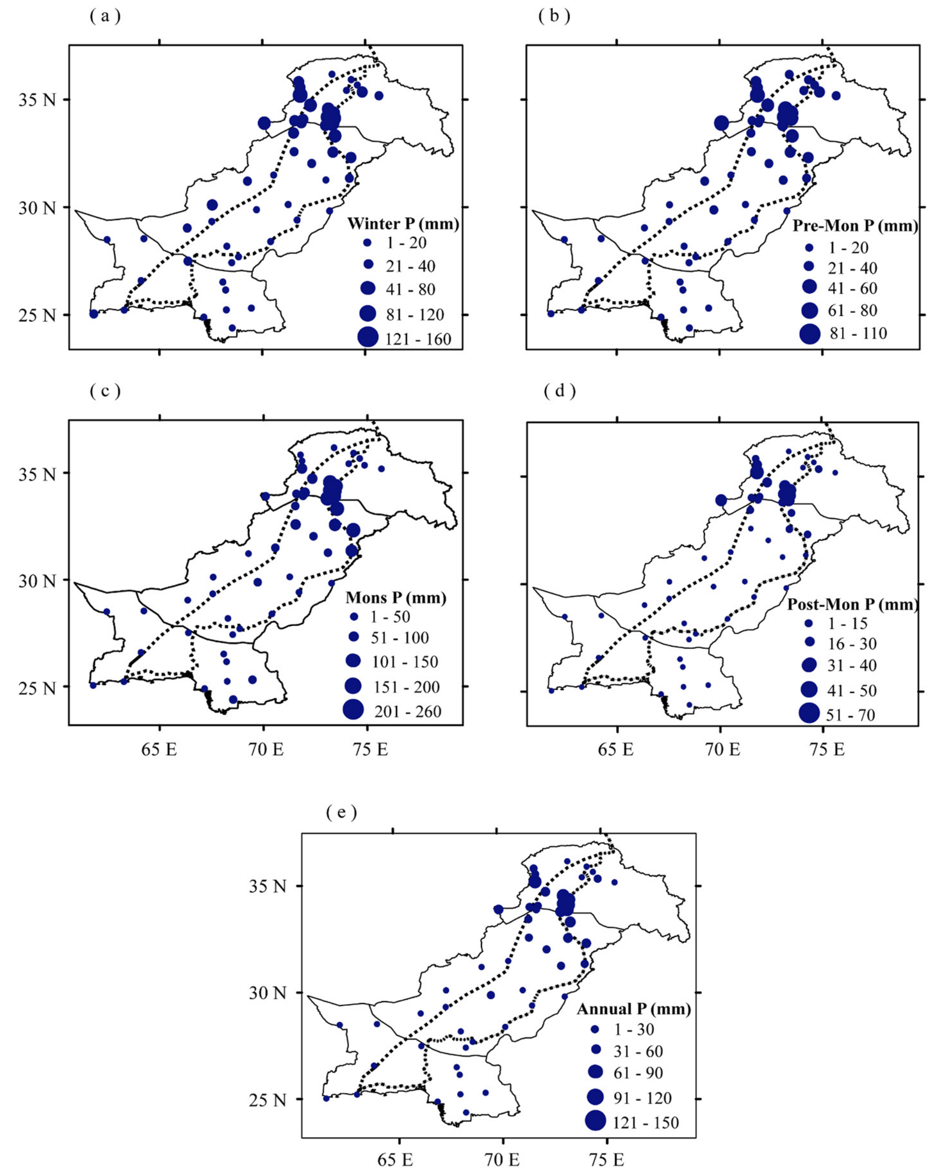

Fig. 3. Spatial distribution of seasonal and annual precipitation during 1980–2016; (a) winter, (b) pre-monsoon, (c) monsoon, (d) post-monsoon, (e) annual.

annual precipitation in the target regions of the study area during the period of 1980–2016. The analysis represents that the stations located in R-1 received the highest precipitation amount in all seasons and annual precipitation budget, because it is the monsoon and westerlies core region of the country (Asmat and Athar, 2017; Wang et al., 2011). The stations located in the eastern part of the R-2 receive high precipitation during winter, pre-monsoon, monsoon seasons and annual precipitation budget, as they are located in the proximity of the monsoon core region (Iqbal and Athar, 2018). Due to closeness to westerlies dominated region (Hussain and Lee, 2009), the stations located in the southwestern parts of the R-2 also receive the maximum precipitation during winter season. The remaining parts of the R-2 and R-3 and receive a limited amount of precipitation in all seasons and annual precipitation budget.

4.3. Temporal variation of seasonal and annual precipitation

The temporal variation and MK monotonic trends of annual and seasonal precipitation during 1980–2016 are shown in Fig. 4 and Table 2. The temporal variation of precipitation shows that the maximum winter, pre-monsoon and annual precipitation were recorded in 1990s, while the maximum monsoon and post-monsoon precipitation were recorded during the periods of 2010–2016 and 1980–1989, respectively. The minimum monsoon, post-monsoon and annual precipitation were occurred during the periods of 2000–2009. The minimum winter and pre-monsoon precipitation were observed during the periods of 2010–2016 and 1980–1989, respectively.

The regional analysis of seasonal and annual precipitation trends were presented in Table 3. The results indicate that the trends of winter and annual precipitation have been decreased in R-1 at the rates of −0.33 and − 0.03 mm per year, respectively, while the pre-monsoon, monsoon and post-monsoon precipitation show increasing trends at the rate of 0.07, 0.16 and 0.08 mm per year, respectively. In R-2, negative trends were detected in winter (−0.26 mm/year) and post-monsoon (−0.01 mm/year) precipitation, while positive trends were detected in monsoon (0.18 mm/year), pre-monsoon 0.20 mm/year and annual precipitation (0.03 mm/year) time series. Irrespective of R-1 and R-2, the seasonal and annual precipitation of R-3 exhibits a unique trend slope. The temporal analysis indicates that the winter, monsoon, post-monsoon and annual precipitation show decreasing trends at the rate of −0.11, −0.01, −0.02, −0.02 mm per year, respectively, while only pre-monsoon precipitation shows a gentle upward trend of 0.05 mm/

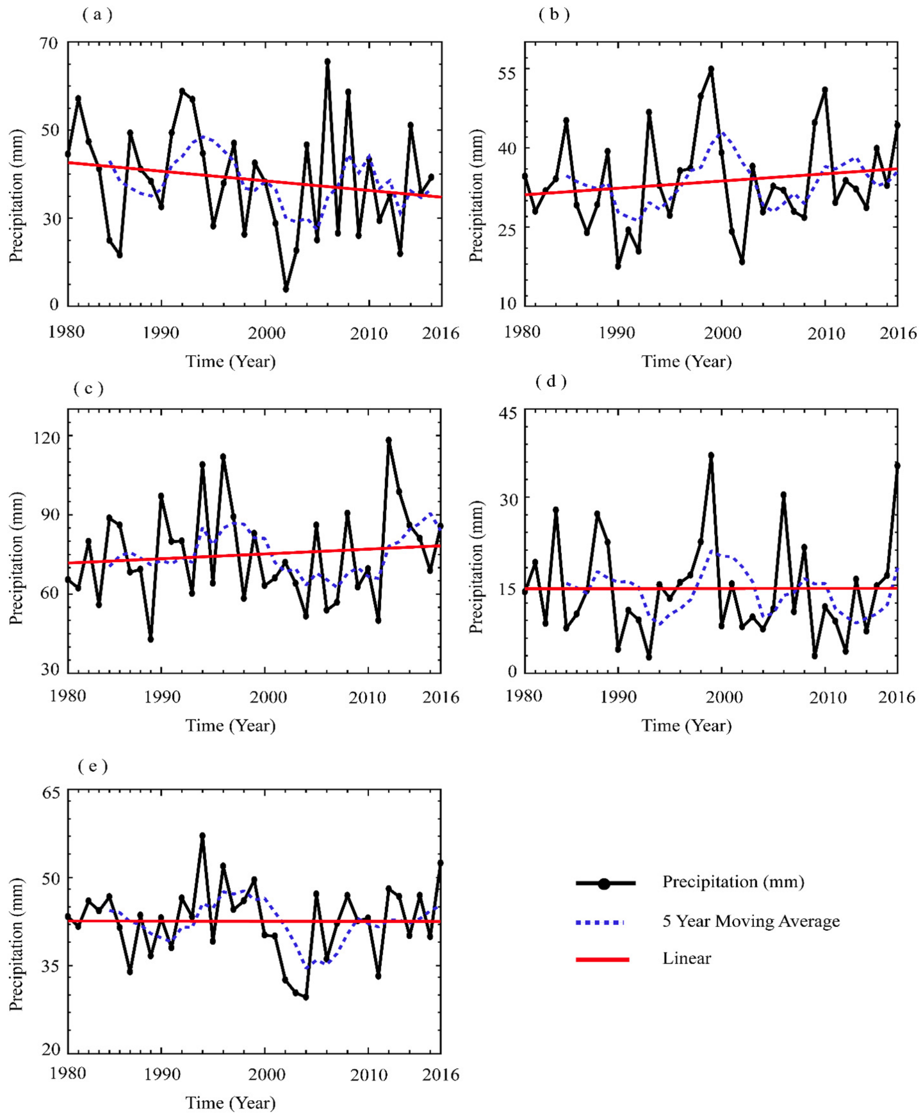

Fig. 4. Temporal variation and linear trend of seasonal and annual precipitation during 1980–2016; (a) winter, (b) pre-monsoon, (c) monsoon, (d) post-monsoon, (e) annual.

Table 2
Decadal variations in seasonal and annual precipitation (mm/decade).

	1980–89	1990–99	2000–2009	2010–2016
Winter	398.07	429.80	356.95	212.69
Pre-Monsoon	312.65	366.76	321.73	241.02
Monsoon	715.45	798.37	672.85	588.23
Post-Monsoon	154.24	149.89	127.58	102.55
Annual	420.47	456.04	390.34	307.21

Table 3
Regional trend analysis of precipitation (mm/year).

	Winter	Pre-monsoon	Monsoon	Post-monsoon	Annual
Region-1	−0.34	0.08	0.16	0.09	−0.04
Region-2	−0.26	0.21	0.18	−0.01	0.04
Region-3	−0.11	0.06	−0.01	−0.02	−0.03
Whole Country	−0.26	0.13	0.14	−0.01	0.02

year during the study period.

4.4. Spatial distribution of seasonal and annual precipitation trends

The spatial distribution of trends for seasonal and annual precipitation over the CPEC region is shown in Fig. 5. In winter precipitation, the negative trend is obvious over the whole country; however, some of the stations located in the southeastern parts of R-2 and R-3 exhibit a slight positive trend (Ali and Ahmad, 2015; Hanif et al., 2013). The analysis indicates that 39 stations show negative trends while 14 stations show positive trend during 1980–2016. The highest negative trend slopes were observed at Dir (−1.86 mm/year), Murree (−1.78 mm/year) and Balakot (−1.39 mm/year) stations, while the highest positive trend slope was observed at Parachinar (1.39 mm/year) station. The results of MK trend test indicated that, 7 stations (Astore, Balakot, Dir, Jiwani, Murree, Quetta and Zhob) show significant negative trends and 1 station (Gupis) shows a significant positive trend at 0.05 significance level. In pre-monsoon precipitation, the positive trend is dominated over the whole region during the study period. The spatial distribution of trend shows that the density of stations with negative trend is high in R-1 and R-3 while the number of stations with positive trend is high in R-2. The results are consistent

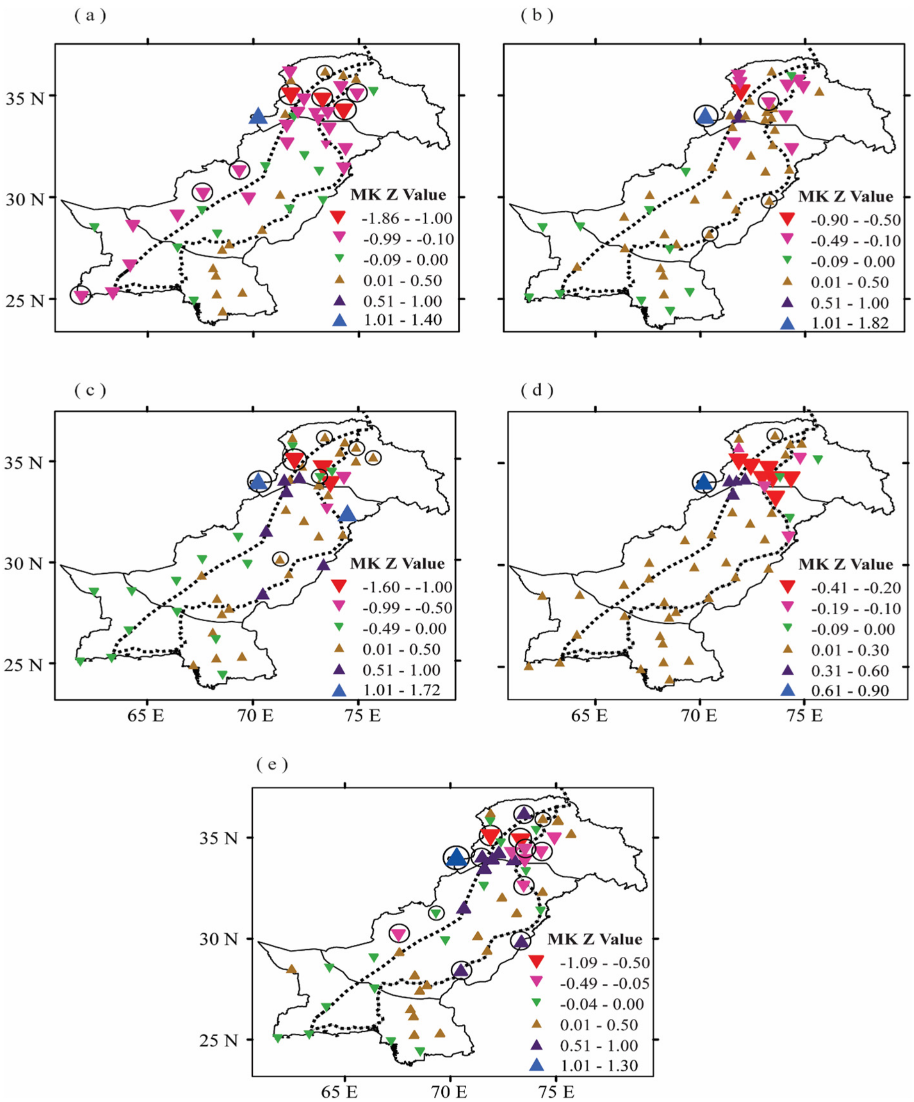

Fig. 5. Spatial destitution of seasonal and annual precipitation trend during 1980–2016; (a) winter, (b) pre-monsoon, (c) monsoon, (d) post-monsoon, (e) annual (The black circles indicate significant trends at α = 0.05).

with the findings of (Ahmed et al., 2017; Asmat et al., 2017; Hanif et al., 2013; Hussain and Lee, 2014). The results of trend analysis indicated an increasing (decreasing) trend of pre-monsoon precipitation at 40 (13) stations. The maximum positive trend was observed at Parachinar (1.82 mm/year) station, while the maximum negative trend was observed at Dir station (−0.90 mm/year). According to the MK trend test, 3 stations (Parachinar, Bahawalnagar, Khanpur) have been found with significant positive trend, while 1 station (Balakot) has been found with significantly negative trend.

The trend analysis of monsoon precipitation trend shows an increasing (decreasing) trend at 31 (22) stations. In R-1, the trend nature is dynamic and fluctuates from station to station. In R-2, majority of the stations show positive trend, except the stations located in south-western parts, while in R-3, majority of the stations exhibit negative trend. Related studies conducted by (Ahmed et al., 2017; Ali and Ahmad, 2015; Asmat and Athar, 2017; Hanif et al., 2013; Hartmann and Buchanan, 2014) have reported similar results. The most positive trends were observed at Parachinar and Sialkot stations at the increasing rates of 1.71 and 1.13 mm per year, respectively. The maximum negative trends were found at Balakot, Dir and Gahridopatta stations at the decreasing rates of −1.56, −1.37, −1.25 mm per year, respectively. Regarding the MK monotonic trend test, 5 stations show significant positive trend (Bunji, Gupis, Parachinar, Multan, Sakardu), while 2 stations (Dir, Kakul) show significant negative trend during the study period. In post-monsoon precipitation, the positive trend is dominated over the whole country, especially the stations located in the R-2 and R-3. However, in R-1, the trend nature is very dynamic and fluctuates from station to station. The overall analysis of the post-monsoon precipitation shows that 35/18 stations have positive/negative trends. The maximum negative trend magnitudes were detected at Gahridopatta, Dir, Saidu Sharif, Murree, and Kakul stations at the decreasing rates of −0.41, −0.34, −0.32, −0.31 and −0.29 mm per year, respectively. The maximum positive trend value was observed at Parachinar (1.71 mm/year) station. Regarding the results of MK trend test, 2 stations (Parachinar, Gupis) show significantly positive trend at 0.05 significance level.

The trend analysis of annual precipitation represents a mixture of positive and negative trends during the period of 1980–2016. The analysis indicates an increasing (decreasing) trend at 28 (25) stations in annual precipitation time series. In R-1 and R-2, most of the stations show positive trend; however, the trend nature is highly dynamic at elevated stations as compared to stations located at plain areas of these regions. Similar results were reported by (Ahmed et al., 2017). This variation could be the results of lack or poor management of hydro-meteorological data in mountainous region (Pellicciotti et al., 2012; Ren et al., 2017; You et al., 2017) In R-3, majority of the stations show

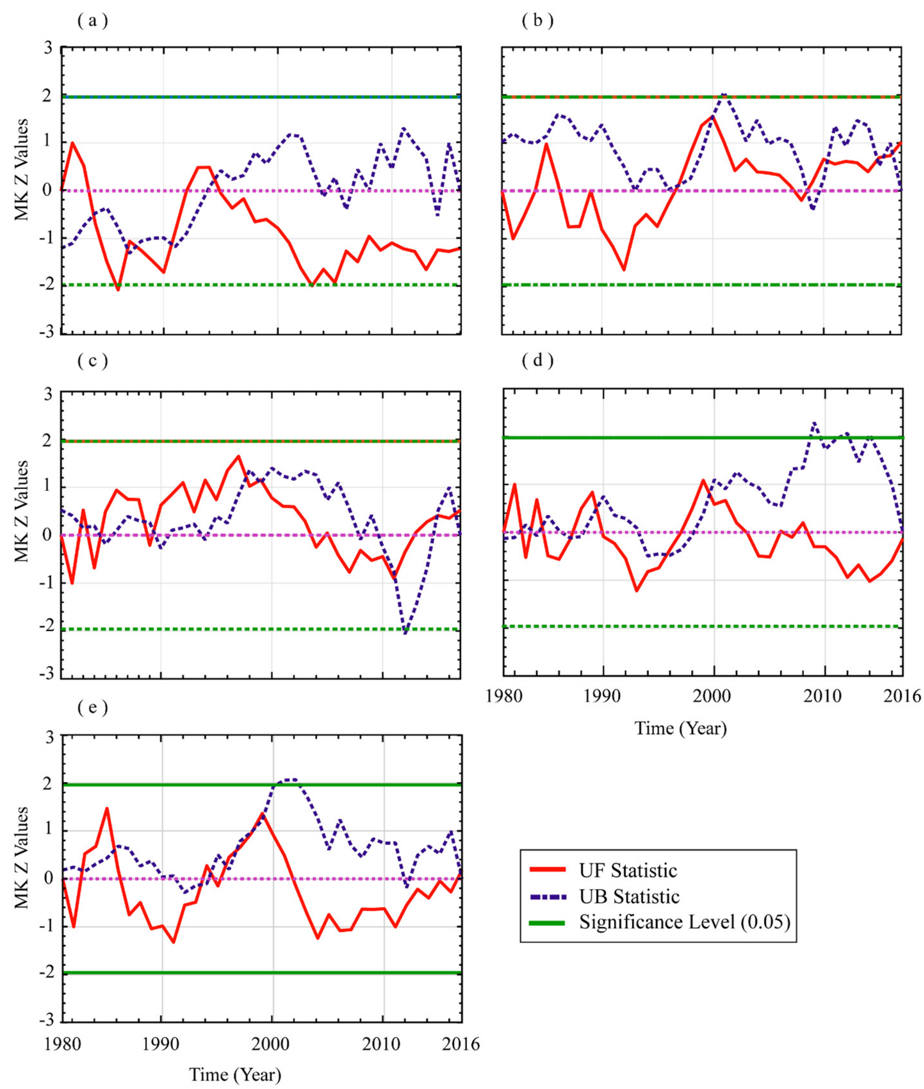

Fig. 6. Abrupt change of seasonal and annual precipitation trend during 1980–2016; (a) winter, (b) pre-monsoon, (c) monsoon, (d) post-monsoon, (e) annual.

negative trend; however, some of the stations located in the south-eastern part of the region were observed with positive trends. The results are in agreement with the findings of (Hanif et al., 2013; Hussain and Lee, 2013). The overall trend analysis of the annual precipitation shows that the maximum negative trends were detected at Dir (−1.09 mm/year) and Murree (−0.87 mm/year) stations, while the highest positive trend value was detected at Parachinar (1.28 mm/year) station. The results of MK monotonic trend test indicate that the trend is significant at 13 stations out of which, 6 stations have significant positive trends (Bahawalnagar, Chilas, Gupis, Khanpur, Parachinar, and Peshawar), while 7 stations (Balakot, Dir, Jhelum, Kakul, Murree, Quetta, Zhob) have significant negative trend.

4.5. Mutation of seasonal and annual precipitation trend

The abrupt shift in climate means transition of climate from one stable state to another (Xu et al., 2018). This rapid change in climate occurred when climate system crosses the threshold level due to some external forces, and trigger a change to a new state at a rate determined by the climate system (Liu et al., 2016; Matyasovszky, 2011). To detect the abrupt changes in temporal trends of seasonal and annual precipitation time series, the SQMK test was used. The UF and UB series were obtained at the confidence interval of 95% (corresponding to the statically significance level $\alpha = 0.05$). The results of abrupt change in seasonal and annual precipitation trends during the study period are shown in Fig. 6. The shift in winter precipitation trend is more rapid and complex during the period of 1984 to 1995. A steep downward shift was observed during 1984, followed by gentle upward and downward shifts during the periods of 1986 and 1987, respectively. A sharp upward/downward change was detected during 1991/1995. In pre-monsoon precipitation, the mutations in precipitation trend were very abrupt started since 1997. A rapid upward/downward shift was detected in 1997/2000. Moreover, many slight upward shifts were detected during the periods of 2009 to 2016.

In monsoon precipitation, the mutations in trend were very complicated during the starting years of the study period. In the first decade, a mixture of slight upward and downward shifts has been experienced in monsoon precipitation. Major rapid decreasing and increasing shifts were detected during 1989 and 2011, respectively. Many studies have reported that the Asian and Indian monsoon systems exhibit a coherent variability across different timescales, from inter-seasonal, inter-annual, inter-decadal, centennial, millennial, and up to orbital and tectonic timescales over the Tibetan Plateau and South Asia (Kripalani et al., 2007; Kripalani and Kulkarni, 2001; Latif et al., 2017; Wang et al., 2017). The primary driver of monsoon systems is solar insolation, and the specific features in the underlying surface, such as land-sea distribution, topography, and oceanic circulations (Wang et al., 2014). These factors are mainly responsible for monsoon

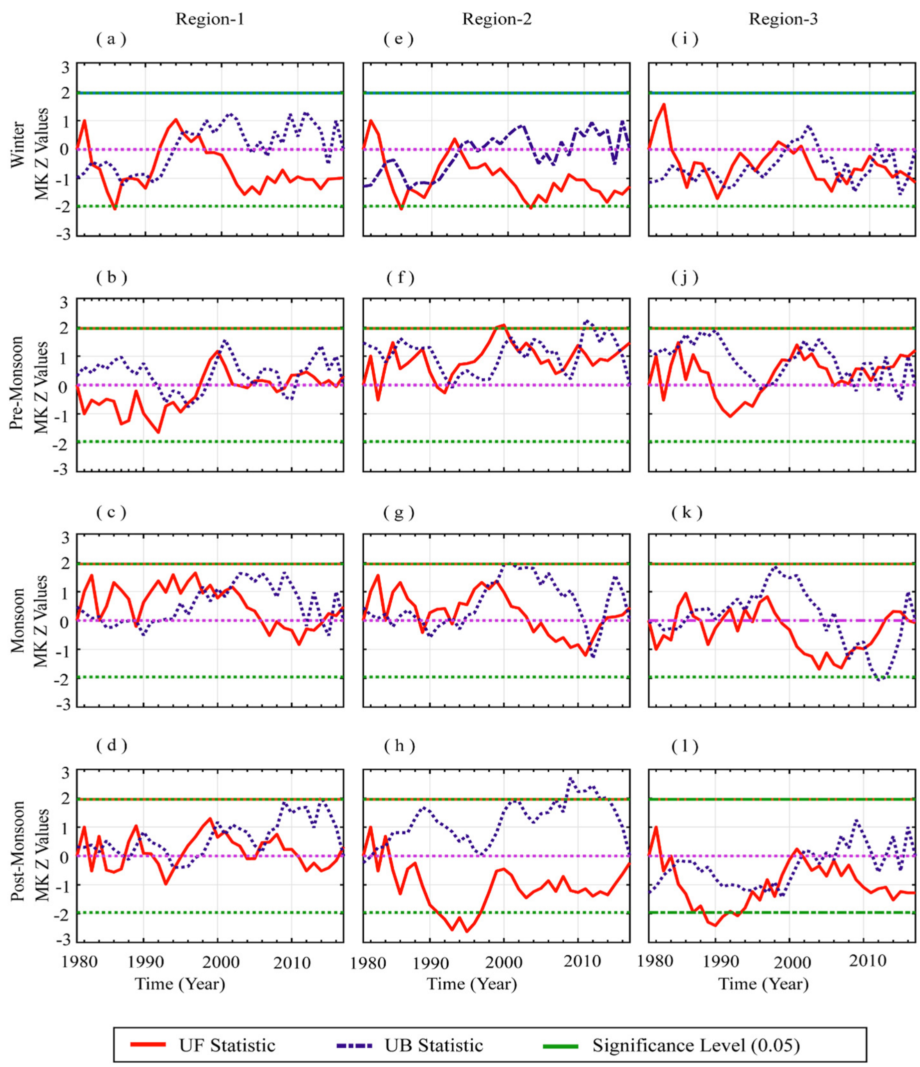

Fig. 7. Abrupt change of seasonal precipitation trend in sub-climatic regions during 1980–2016; (a) R-1 winter, (b) R-1 pre-monsoon, (c) R-1 monsoon, (d) R-1 post-monsoon, (e) R-2 winter, (f) R-2 pre-monsoon, (g) R-2 monsoon, (h) R-2 post-monsoon, (i) R-3 winter, (j) R-3 pre-monsoon, (k) R-3 monsoon, (l) R-3 post-monsoon.

variability in the target region (Hanif et al., 2013; Latif et al., 2017; Yamada et al., 2016). Meanwhile, the inter-annual and multi-decadal variability of monsoon may also arise from dynamic and thermo-dynamic feedback processes within the climate system (Wang et al., 2017). These feedback forces include; El Niño-Southern Oscillation (ENSO), the Atlantic multi-decadal oscillation (AMO), and inter-decadal Pacific Oscillation (IPO), which cause monsoon variability mainly on inter-annual to multi-decadal time scales over different regions including Pakistan (Kripalani et al., 2007; Priya et al., 2015, 2017; Wang et al., 2012). In post-monsoon precipitation trend, the gentle up and down shifts were observed during the first decade while the steep mutations were experienced after 1989. Major rapid downward shifts were detected during 1989 and 1999 while an abrupt positive change was found during 1996. Irrespective of seasonal precipitation, the mutations of annual precipitation were more complicated during the second decade of the study area. During 1982, a steep increase was observed in annual precipitation trend followed by an abrupt decreasing shift during 1986.

4.6. Mutation of seasonal precipitation trend in sub-regions

Fig. 7 shows the results of rapid change of seasonal precipitation trends over sub-regions of the study area. The seasonal precipitation in the different sub-regions had different positions over the study period. In R-1, the abrupt changes in winter precipitation trend were observed in three periods. In 1983 and 1994, rapid decreasing changes were detected, while in 1991, a sharp upward shift was detected. In R-1, the major abrupt changes in pre-monsoon precipitation were detected during 1996–2000. A sharp increasing shift was observed in 1996 followed by a steep downward shift in 2000. Similarly, a steep downward shift was found in monsoon precipitation in R-1 during 2002. In R-1, the post-monsoon precipitation shows a complex and rapid mutations during the study period. However, the major downward and upward shifts have been observed during 1989 and 1994, respectively.

In R-2, the trend of winter precipitation shows three major mutation points. Abrupt downward shifts were detected in 1984 and 1993, while a sharp positive change was observed during 1990. The pre-monsoon and monsoon precipitations of R-2 have dynamic mutation nature throughout the study period; however, a major upward shift was detected in 1993 in the pre-monsoon precipitation, and a steep downward change was observed in monsoon precipitation in 1999. Similarly, in R-2, the post-monsoon precipitation shows an abrupt downward shift in 1984. In R-3, all seasonal precipitations show a dynamic mutation nature during the study period. The winter precipitation shows two mutation points i.e. the upward shift in 1991 and downward shift in 1999. In pre-monsoon precipitation, abrupt increasing and steep decreasing mutations were observed during 1997–2001, respectively. Two mutation points were detected in monsoon precipitation of R-3 i.e.

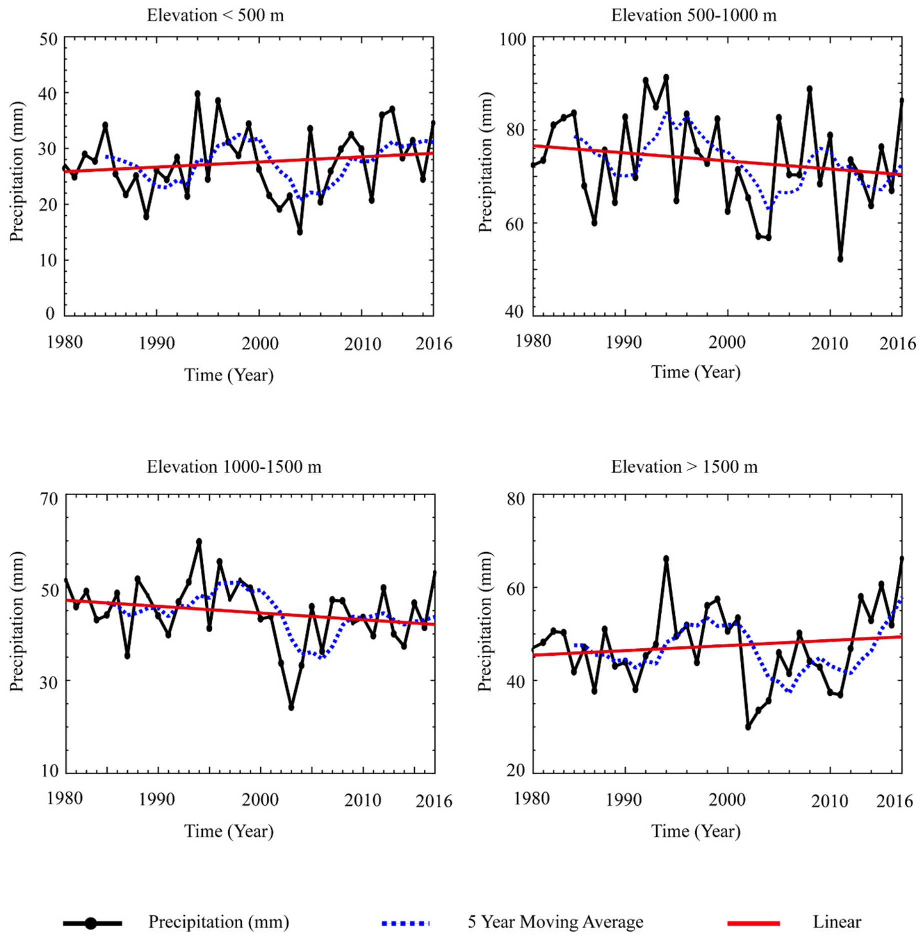

Fig. 8. Trend of long-term precipitation in different elevation zones during 1980–2016.

an abrupt upward trend in 1987 and abrupt downward trend in 2010. The post-monsoon precipitation of R-3 shows three shifting points during 1980–2016. The two abrupt downward changes were detected in 1985 and 2001, while a single positive shift was detected during 1998.

4.7. Trends of long-term precipitation in different elevations

The trend of annual precipitation was studied with respect of different elevation zone. The study area has been divided into 4 elevation zones: < 500 m, 500–1000 m, 1000–1500 m, and > 1500 m. The MK trend test was used to detect the significant test while the SS test was applied to calculate the slope of trend in each elevation. The results of the MK trend and SS tests for long-term precipitation in different elevation zones are shown in Fig. 8. The annual precipitation in the different elevations showed a mixture of trends during the study period. The annual precipitation shows increasing trend at a test level of 0.05 ($-1.96 \leq Zc \leq 1.96$) in the elevation zones of ≤500 m and ≥ 1500 m. The trend shows an increasing nature in the elevation zones of ≤500 m (0.13 mm/year) and ≥ 1500 m (0.09 mm/year), while decreasing in the elevation zones of 500–1000 m (−0.17 mm/year) and 1000–1500 m (−0.13 mm/year).

4.8. Relationship between precipitation trends and elevation

Related studies have found a positive relationship between precipitation and elevation (Guo et al., 2016; Li et al., 2011). However, many studies have also reported a negative correlation between precipitation and elevation for annual, monsoon, winter, and spring precipitation (Hanif et al., 2013; Xu et al., 2018; Zhang et al., 2007). The reasons behind this dynamic relationship is still under investigation and need to be explored with clear scientific picture for understandings. However, some of the experts reported that this dynamic variation in precipitation trend with respect to elevation could be the result of shifting of westerlies disturbance and monsoon weather systems in the study area (Asmat et al., 2017; Dimri et al., 2015; Wang et al., 2011). Moreover, the orographic and physiographic nature of the region could also plays a vital role in variation of precipitation trend in the highly elevated regions (Álvarez-Rodríguez et al., 2017). Fig. 9 shows the correlation between precipitation trend magnitude and elevation in the study area. The analysis indicates that the winter, monsoon and annual precipitation trends show a significant negative correlation with elevation, while the trends of pre-monsoon and post-monsoon precipitation show a significant slight positive correlation with elevations. The results are in agreement with the findings of (Asmat and Athar, 2017; Hanif et al., 2013; Hartmann and Buchanan, 2014).

5. Conclusion

This paper analyzed the spatio-temporal trends in seasonal and annual precipitation in CPEC and the sub-climatic regions along the CPEC routes during 1980–2016. The temporal analysis of precipitation trends show that the winter and post-monsoon precipitation exhibit an insignificant decreasing trend while the pre-monsoon, monsoon and annual precipitation show an increasing trend during the study period. The spatial distribution of trend for seasonal and annual precipitation over different sub-climatic regions indicates that the magnitude of trend fluctuates from region to region and station to station. A decreasing

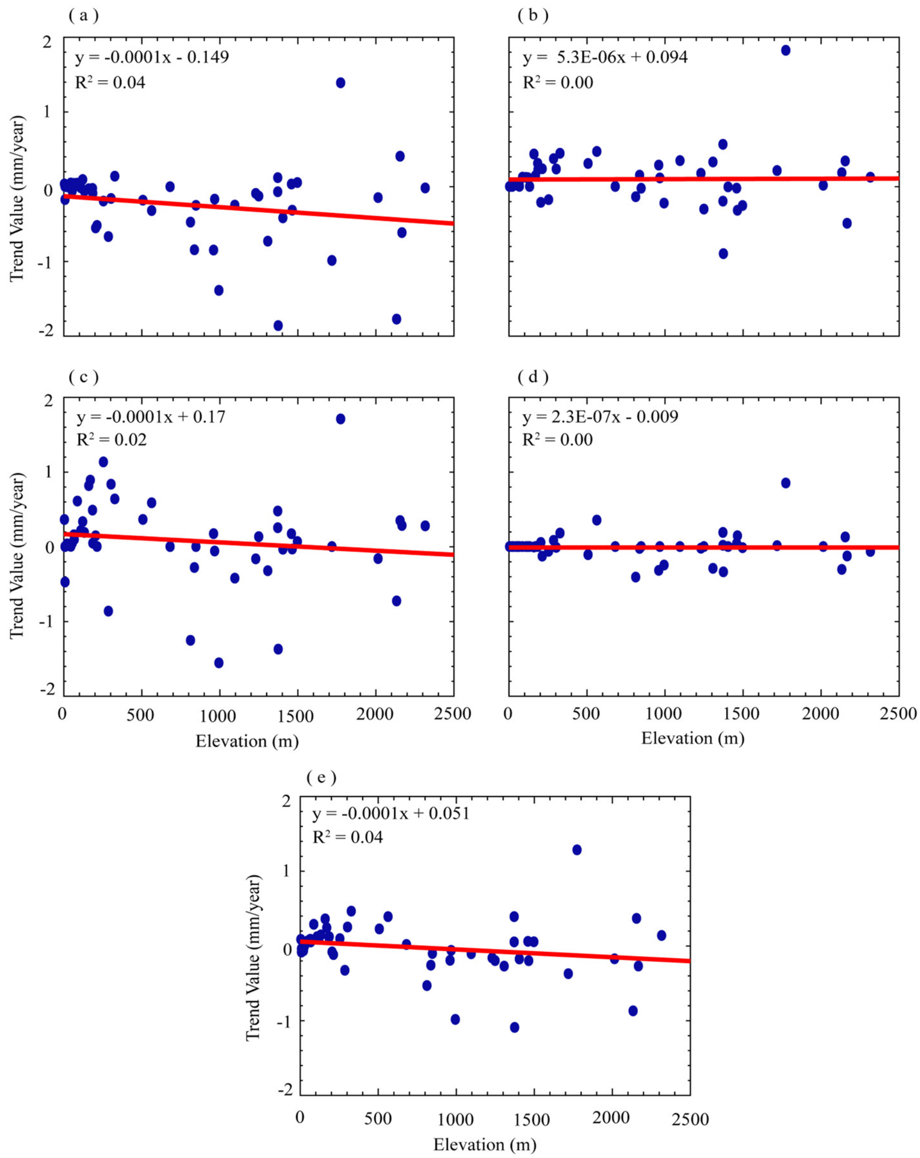

Fig. 9. Correlation between elevation and trend of seasonal and annual precipitation during 1980–2016; (a) winter, (b) pre-monsoon, (c) monsoon, (d) post-monsoon, (e) annual.

trend is obvious in winter precipitation while the pre-monsoon, monsoon and post-monsoon precipitation dominate by positive trends during 1980–2016. The annual precipitation shows a mixture of positive and negative trends. The maximum number of stations with significant negative trend was found in winter (7) while the highest numbers of stations with significant positive trend were observed in monsoon season (5). The mutations in temporal trends of seasonal and annual precipitation exhibit a complex and dynamic behavior during the study period. In winter precipitation, the abrupt downward changes were observed in1984 and 1995 with an upward shift in 1991. The rapid change points in pre-monsoon precipitation were detected after 1996s with an upward/downward shift in 1997/2000. The monsoonal precipitation exhibits two abrupt changing points in temporal trend with a downward/upward shift in 1989/2011. In temporal trend of post-monsoon precipitation, the rapid downward and upward changes were detected during 1989–1999, respectively. Two major mutations points were found in annual precipitation: a steep increase in 1982 and abrupt decrease in 1986. This study also provided details on the mutations in temporal trends in different sub-climatic regions of the CEPC routes during 1980–2016. The long-term precipitation exhibits a dynamic trend with respect to elevation. The trend of annual precipitation increases at elevation ≤500 m and ≥ 1500 m, while decreases at elevation ranges from 500 to 1000 m and 1000–1500 m. Moreover, the winter, monsoon and annual precipitation show negative correlation with elevation, while the pre-monsoon and post-monsoon precipitation show positive correlation with elevation in the study area. This study provided details on the variability of precipitation trends in the region. Further studies should focus on climatic drivers responsible for changes in precipitation trends in the region.

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